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Effect of Visual Acuity on Target Acquisition

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FOREWORD

Two laboratory experiments on target acquisition with direct vision were conducted between February and April 1976. The work was requested by the U.S. Army Training and Doctrine Command to (1) determine the relative effects of far visual acuity and several other factors on target acquisition performance, and (2) to generate curves relating target acquisition performance to far visual acuity. The project was supported by MIPR W26RIP603.

This report has been reviewed for technical accuracy by Ronald A. Erickson and is released at the working level for information purposes only.

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Two laboratory experiments were conducted. The purpose of the first experiment was to determine the effect of far visual acuity on target acquisition performance relative to 10 other factors. A rank ordering was achieved by employing a screening technique (partial factorial). Far visual acuity ranked second behind slant range in most analyses.

~~(U)~~ The second experiment was conducted to generate curves which related search times and detection probability to far visual acuity at different levels of slant range, masking, and observer experience. A full factorial design was employed to test the factors. Subjects with better than 20/20 acuity located the targets at least twice as fast as subjects with 20/40 and 20/50 acuity. It was also found that the effect of far visual acuity depended upon the observer-to-target range and upon the extent of target masking.

CONTENTS

INTRODUCTION

Great effort and substantial amounts of money are being spent to increase the effectiveness of armored tanks and to reduce their vulnerability. In this context, part of the total tank system which is receiving increasing attention is the capability of the crew members to perform the tasks required in a tank.

One of the primary tasks of tank crewmen is the detection and identification of targets. However, there are currently no stringent standards of visual acuity required of tank crewmen Should some standards be set for personnel selection and maintenance in order to insure optimum performance of the target acquisition task?

Specifically, the following questions must be answered.

1. Do differences in visual acuity actually result in significant performance differences?

2. How much of the differences in performance that occur in the real world is due to visual acuity and how much to other factors in the environment?

3. How does performance vary as a function of visual acuity?

OBJECTIVES

The objectives of this study were to (1) determine the importance of visual acuity on target acquisition performance relative to other factors, and (2) generate curves that indicate how performance varies as a function of visual acuity.

The factors other than visual acuity that were tested for the relative strength of the effect they have on target acquisition were:

- Range to target
- Target type
- Masking
- Target/background (T/B) contrast
- Paint scheme
- Target density
- Target orientation
- Observer familiarity with terrain
- Depth perception
- Color vision

OVERVIEW

The study was conducted in two phases. In the first phase, a screening experiment was conducted in which two levels of each of the above 11 independent variables were tested. Subjects attempted to locate and identify 1:84 scale model targets on a terrain model within a 1-minute time limit. The subjects were scored for correctly locating the target and correctly identifying it given a correct location.

In the second phase, a factorial experiment was conducted. A subject with one of four levels of visual acuity was required only to locate a scale-model, pattern-painted tank on a terrain model within 30 seconds. Each subject saw both masked and unmasked targets at four ranges. The subject was scored on his response time for correct locations and the frequency of correct responses.

EXPERIMENT I

METHOD

Design

A "screening" or "saturated" design was used in this experiment. This approach permits a large number of variables to be investigated so that their relative importance may be ascertained in a very economical manner; that is, using the fewest number of experimental conditions and trials possible. One proponent of the screening design, Simon, has outlined a general approach to the method:

> "Screening studies progress in several stages. The first stage involves a saturated design in which (N – 1) effects will be isolated by using at least N experimental conditions carefully selected from the total factorial design. The effects that are isolated in saturated designs are usually independent estimates of the main effects, each confounded with two-factor and higher interaction effects. For this reason, the basic design must be augmented in the second stage of the screening study, usually by adding N more observations, to isolate the main effects from at least the two-factor interactions. Further observations may be added to *isolate* or at least identify which two-factor interactions are important.
>
> "By this stage, there should be enough information to grossly order the factors and two-factor interactions in terms of the magnitude of their effects on performance. Still the number of measurements taken will have been relatively few, yet with a large number of factors, the precision of the estimates is fairly high. The quality of the data increases as the number of factors increase and so do the savings incurred from using screening designs." [1]

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[1] Air Force Systems Command. *Economical Multifactor Designs for Human Factors Engineering Experiments*, by Charles W. Simon, Display Systems and Human Factors Department, Hughes Aircraft Company, Culver City, CA, June 1973. (Technical Report No. P73-326, publication UNCLASSIFIED.)

In this experiment the effects of 11 factors and four two-factor interactions were eventually isolated. To accomplish this:

1. Sixteen conditions were tested in the basic design.

2. Sixteen conditions were tested in the augmented design.

3. A second basic design (changeover) was included to increase the precision of the estimates; the second basic design was also augmented, increasing the total number of conditions to 64.

4. The order of the trials was partially counterbalanced for trend effects.

A description of the experimental conditions is presented in Appendix A.

The 11 factors of interest were tested with each factor having two levels. The levels that were chosen represented either the points between which a maximum range of performance was expected or between which the factor would normally vary in the environment. Table 1 presents each factor and the value of the two levels.

TABLE 1. Eleven Factors and Two Levels Assigned Each Factor.

Factors	Values	
	−	+
Visual acuity	20/40	20/20
Depth perception	Poor	Good
Color vision	Deficient	Good
Familiarity with terrain	2 trials	14 trials
Slant range (simulated)	1,600 m	800 m
Target type	APC	Tank
Masking	50-75%	None
Target/background contrast*	1.15	2.40
Pattern painting	Pattern	Solid
Target orientation	45 deg	90 deg
Target density	1 target	3 targets

* The equation $C = \frac{\text{Lum(max)} - \text{Lum(min)}}{\text{Lum(min)}}$ was used to compute contrast. The solid-colored targets were almost always darker than the background and the pattern-painted targets were lighter.

Subjects

Sixteen employees of the Naval Weapons Center served as subjects in this experiment. Subjects were chosen on the basis of their far visual acuity and depth perception as measured on a Bausch and Lomb Armed Forces Vision Tester and their color vision as measured by Dvorine Pseudoisochromatic Plates. Table 2 indicates the grouping of subjects based on their visual capabilities. These groupings correspond to the experimental subject conditions.

Of the eight subjects with good visual acuity, five wore glasses; of the eight with poor acuity, two were corrected to 20/50, the rest did not wear glasses.

Four of the subjects had previously served as subjects in a terrain model experiment, although none more recently than 6 months prior to this study.

TABLE 2. Experimental Subject Groups.

Color vision	Visual acuity			
	20/17 or better		20/30 to 20/60	
	Depth perception			
	Normal	Below normal	Normal	Below normal
Normal	2 subjects	2 subjects	2 subjects	2 subjects
Below normal	2 subjects	2 subjects	2 subjects	2 subjects

Where:

Normal depth perception was better than 14 out of 18 correct.
Below normal depth perception was fewer than 5 out of 18 correct.
Normal color vision was 14 out of 14 plates correct.
Below normal color vision was fewer than 4 out of 14 plates correct.

Apparatus

Search Area. The search area was a 2.4-meter-square terrain model simulating an area approximately 200 meters square. It contained numerous trees and shrubs of various types, colors, and heights. Some areas were densely wooded, others were fairly open. The ground cover varied in color from yellows and browns to deep greens. There were some sandy areas, and rock formations were also included.

Lighting. Lighting was provided by two Mole-Richardson Type 3211 Broad Lights with 1,000-watt, 3200°K quartz globes. The total lighting effect was one of a bright day with clearly visible shadows.

Targets. Four types of targets were used in this experiment, two types of vehicles (tanks and armored personnel carriers) each with two paint schemes (monotone, olive drab, and pattern-painted with the recent U.S. MERDC* design). The 1:84 scale models were painted with Pactra brand flat enamel. No identifying marks or stars were painted on the vehicles.

* U.S. Army Mobility Equipment Research and Development Center, Fort Belvoir, VA.

Shutter and Timer. A shutter attached to a small, lightweight desk was used to prevent the subject from seeing the target placed on the terrain and to provide a consistent starting procedure for all subjects. The shutter consisted of a white cardboard frame with a center 10 by 25 cm window, covered by a thin sheet of aluminum when closed. The subject opened the shutter by pulling a cord with his left hand. The catch holding the shutter opened and a spring drew the shutter away from the window. When the shutter was fully open an electronic digital timer would start. The timer would stop at the flip of one of two switches on the subject's desk top. One switch was labeled "TANK"; the other was labeled "APC". Following each trial the subject pulled the shutter back over the window to obscure his view and reset the timer. The entire shutter and timer apparatus was portable, enabling it to be moved to the various test ranges.

At the near range, the subject and apparatus were located on the floor. The simulated elevation of the subject at this point was 50 meters above the target area (as if looking into the area from a ridge). At the far range, the subject and apparatus were located atop a 1.2-meter platform simulating an observer elevation of 118 meters. The different elevations were chosen to maintain a relatively constant aspect angle of the target and terrain. In that way contrast, orientation, and masking were also held constant.

Target Locations. The locations of the targets on the terrain model were chosen for their T/B contrast and their usefulness for masking. Several difficulties were encountered in attempting to provide only two levels of T/B contrast. First, luminances of variegated targets and background cannot be assigned a single value. The contrasts vary around the target edges, as well as within the target edges. Secondly, in this study, the darker colored, solid targets were generally darker than the background, while the lighter, pattern-painted targets were lighter than the background. Ultimately, average luminances of the target and background were used as criteria for the target locations. In addition, black-and-white photographs were taken of all the target types in all the locations. These were presented to several people who were instructed to separate the photos into high and low T/B contrast groupings. In each case, the groupings coincided with the experimental T/B contrast levels.

In this study, targets were masked vertically; that is, the rear half of the vehicle was blocked from view. In all cases, the tread and underside of the hull were visible toward the forward portion of the vehicle.

Procedure

Each s.   was tested for far binocular visual acuity, color vision, and depth perception. He was then seated behind the shutter and given the instructions (Appendix B). The targets were presented to the subject for inspection while the instructions were being read. He was also given the opportunity to practice with the shutter mechanism and switches. He was then given two practice trials followed immediately by the test trials.

The subject's task was to open the shutter when the experimenter called "ready" and immediately begin searching for the target. Upon locating the target, he flipped either the switch marked "TANK" or the one marked "APC" depending on his judgment as to its identity. The subject had 1 minute to locate the target before time was called. After he had located the target and

flipped the switch, he described the target location on the terrain as a means of determining if, in fact, he had actually located the target. Then the subject closed the shutter and prepared for the next trial.

Each subject was administered one condition from the basic design twice, one condition from the augmented design twice, one condition from the changeover design twice, and one condition from the augmented-changeover design twice. The subject was then given four additional practice trials, after which he was considered familiar with the terrain. He was then tested on four different conditions, one each from the basic, augmented, changeover, and augmented-changeover designs. Each condition was again tested twice.

With eight subjects tested on eight conditions, all 64 conditions were tested with half the subjects. Eight additional subjects were tested on the same conditions in the same manner. Each subject, therefore, received 16 data trials (eight conditions and two trials per condition). But two subjects were tested on the same set of conditions so, for each condition, there were four data points. Altogether, over all conditions and subjects, there were 256 data points.

RESULTS

The data were analyzed using three response measures: correct detections only, correct identifications only, and correct detections and identifications. Correct identifications could only have occurred following a correct detection.

Detection, as used here, refers to the response of the subject that he had located the target. Each subject may have used a different level of certainty for deciding whether he should respond or not. Some subjects, therefore, never responded to a false target and some made several mistaken responses.

The data obtained through the use of the screening technique can be used to estimate the effect each factor has on performance relative to the other factors tested. This provides, in essence, the rationale for rank-ordering and scaling the test factors.

The scales presented in this study were normalized to enable them to be compared. The values on the scales were arbitrarily chosen in order to indicate the relative strength of the effects of the factors. A factor that ranked high on both iterations of the experiment probably had a strong effect; a consistently low-ranked factor was, on the other hand, probably unimportant. Factors with similar ranks may well vary from iteration to iteration, but large deviations are not as likely to occur.

Figure 1 presents the rank order and relative strengths of the 11 factors for the two subject groups combined. The number of correct detections and identifications were both used in the construction of this figure. The most notable results in Figure 1 are the strong effects of slant range and visual acuity, and the rather weak effects of T/B contrast, pattern painting, and terrain familiarity. The factors also seem to divide nicely into three levels, strong, medium, and weak.

Dividing the subjects into the two experimental groups changes the order somewhat, as indicated in Figures 2 and 3. Nonetheless, with the exception of masking, the factors can be roughly divided into three similar levels. The factor of central concern in this experiment was visual acuity and that factor consistently ranked high, having a strong effect in both subject groups.

Visual acuity was also found to play an equally important role in both detection and identification. Figures 4 and 5, in which the two subject groups are combined, are similar in most respects, indicating that the factors act in a consistent fashion on both detection and identification, as defined here. The major exception is target density. Clearly the more targets present, the more likely one will be acquired. Therefore, it would be expected that the number of targets would have a strong effect on detection. On the other hand, additional targets would not necessarily provide more information useful in identification, so density would have little effect. (See Figures 4 and 5.)

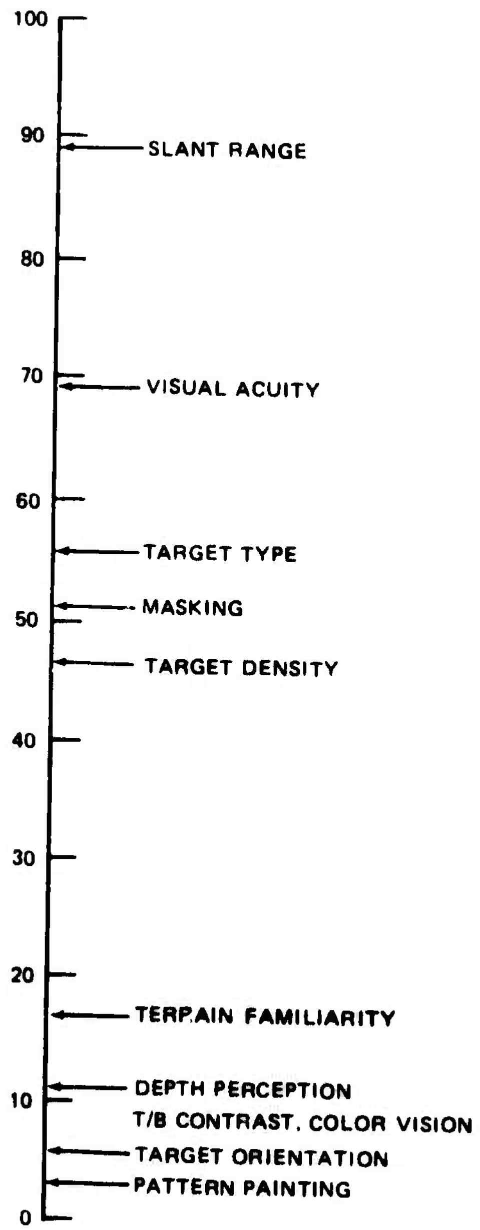

FIGURE 1. Relative Strength of Effect of the Factors for Identification and Detection Data.

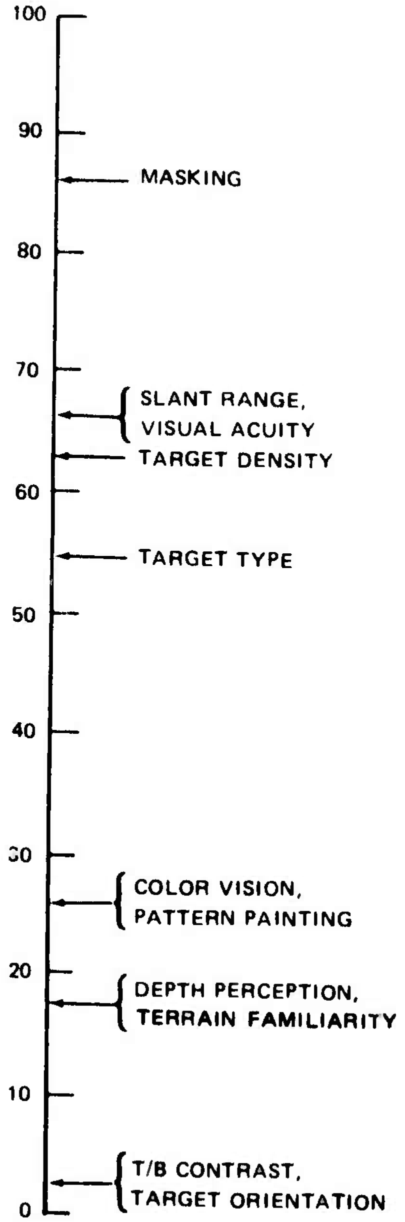

FIGURE 2. Relative Strength of Effect of the Factors for Subject Group A.

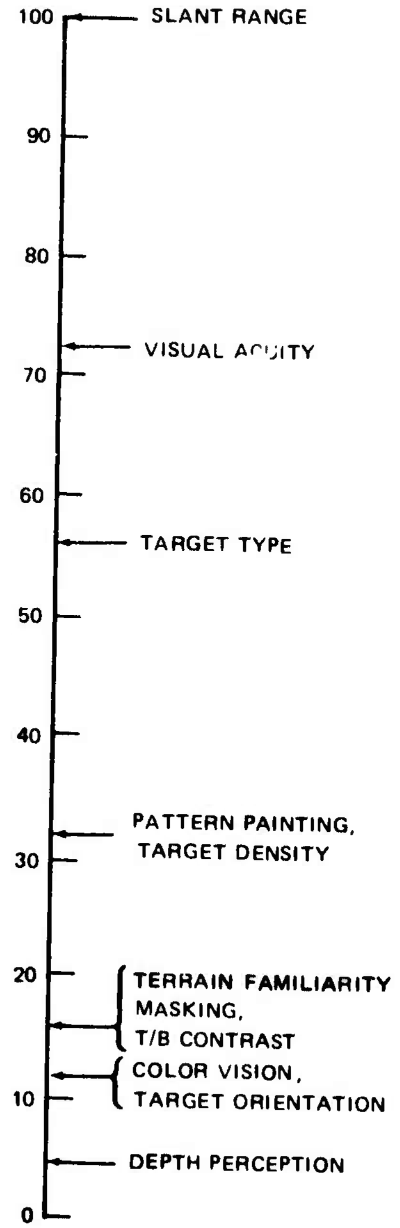

FIGURE 3. Relative Strength of Effect of the Factors for Subject Group B.

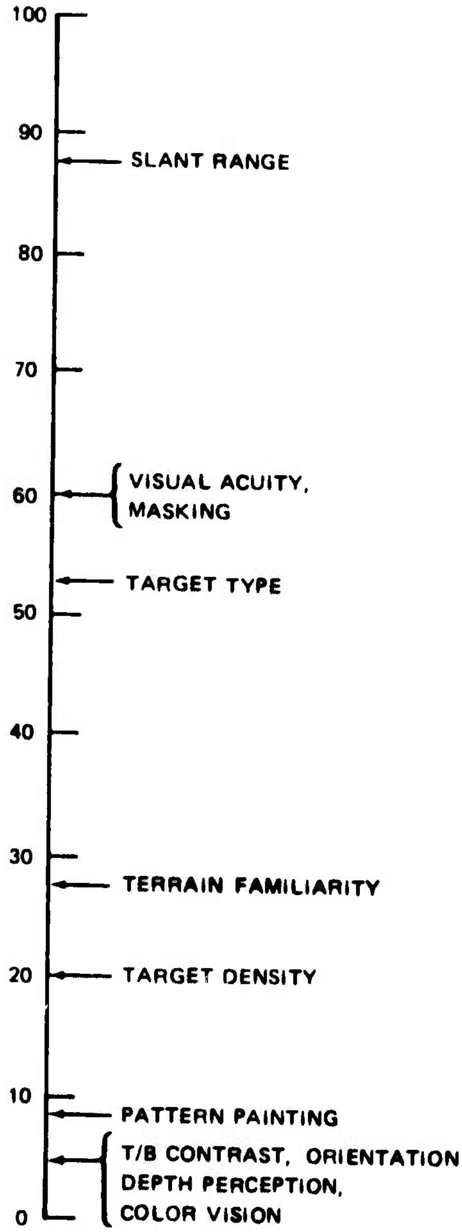

FIGURE 4. Relative Strength of Effect of the Factors for the Identification Data.

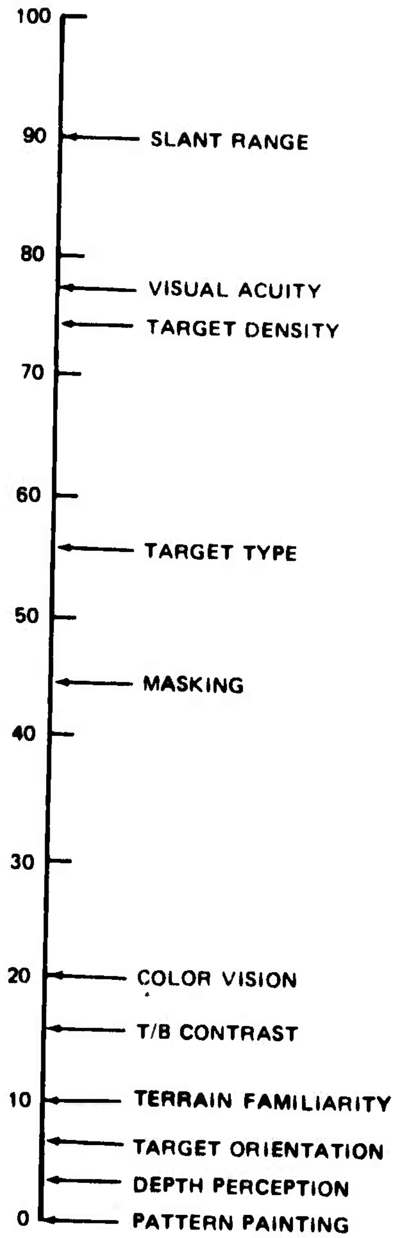

FIGURE 5. Relative Strength of Effect of the Factors for the Detection Data.

DISCUSSION OF RESULTS

The strong effect of range on target acquisition is not surprising. However, visual acuity had a much stronger effect than expected. This is especially so since the two levels of acuity, 20/20 and 20/40, were not considered very disparate by the experimenters. The implications of such a discovery is that target acquisition performance is substantially related to factors under our control.

Also of interest are the factors found to have little effect under the conditions tested in this experiment. Color vision, target orientation, and paint scheme have had little effect in other studies and these results are supportive. Depth perception, on reflection, would not likely have a strong effect since, at ranges of even 400 meters, objects do not appear to have much depth.

Target/background contrast was expected to have a greater effect than the results indicated. That it did not is probably more indicative of the small difference between the contrast levels chosen than the strength of the factors. The assignment of one average value of T/B contrast for a target in its background may be unrealistic, since one aspect of the target with high contrast may make a generally low-contrast target conspicuous. However, as indicated previously, there was a subjective difference in contrast between the two levels. It might also be questioned whether the levels tested could be expected operationally. If they are reasonable extremes, then T/B contrast may, in fact, be relatively unimportant in target acquisition.

Familiarity with the terrain also had little effect on performance. This again may have been due to a small difference in the factor levels. This factor, since it can be controlled operationally, deserves further study.

EXPERIMENT II

METHOD

Design

A 2 x 2 x 4 x 4 factorial design with repeated measures on two factors was used to estimate the effects of subject experience (2), masking (2), range to target (4), and visual acuity (4) on search time and probability of acquisition. Table 3 illustrates this design.

Subjects

Thirty-two employees of the Naval Weapons Center served as subjects. Half of them had participated in Experiment I of this study and were familiar with the task and terrain. For the purposes of this study, they were considered "experienced."

Subjects with deficient color vision and depth perception were not disqualified as subjects based on the previous study indicating that no significant differences occurred due to those factors.

TABLE 3. Experimental Design.

Experience	Visual acuity	Masking							
		Yes				No			
		Range, m							
		400	800	1,200	1,600	400	800	1,200	1,600
Yes	20/20	Subject 1	Subject 1	Subject 1	. . .	. . .			
	20/30	Subject 2	Subject 2	Subject 2	. . .	. . .			
	20/40	Subject 3	Subject 3	Subject 3					
	20/50	Subject 4	Subject 4	Subject 4					
No	20/20	Subject 5							
	20/30	Subject 6							
	20/40	Subject 7							
	20/50	Subject 8							

Apparatus

With the exception of the target and digital timers, the same apparatus that was used in Experiment I (search area, lights, shutter) was also used in this experiment.

The pattern-painted, 1:84 scale model tank used in Experiment I was the only target employed in this phase of the study. It was always oriented at a 45-degree angle facing the subject in one of two locations.

The two locations were arranged so that they were at an equal range from the subject at all times; they had, subjectively, equal values of T/B contrast. They were on sandy soil with a tree background. The only respects in which they differed was that one location was located near the center of the search area and one was closer to the edge, and in one location low bushes masked the tread and underside of the hull. The first difference was not considered important based on data obtained from other studies using the terrain model. The second difference was referred to as tactical masking and it should be noted that it differs in type from the vertical masking of Experiment I.

The subject was prevented from learning that only two locations were of interest by the use of other locations in unscored trials. In this way the subject could not predict where the target would appear.

A stop watch was used to measure search times in this phase of the study.

Procedure

Each subject's far binocular visual acuity was tested and, if necessary, it was adjusted with optometric diagnostic lenses to meet the level of visual acuity required for a particular set of conditions. The subject was then assigned to one of eight groups, depending on his particular level of visual acuity and experience.

The subject was seated behind the shutter and instructions similar to those used in the first experiment were read. He was allowed to inspect the target and practice with the shutter mechanism and switches. He then received one practice trial, following which the test trials were administered.

The subject's task was to open the shutter when the experimenter called "ready," and immediately begin searching for the target. When the shutter opened, a stop watch was started. The watch was stopped when the subject flipped a switch on the desk top, indicating that he had located the target. He then described the location of the target on the terrain as a means of determining if, in fact, he had actually located the target Following each trial, the subject pulled the shutter back over the window and reset the switch.

Each subject was given 30 seconds to locate the target. If there was no response in the time allowed, the trial was terminated and another trial was administered.

The subject-to-target depression angle was held at approximately 4.6 degrees below the horizontal plane at each range tested.

The ranges at which the subjects were tested were partially counterbalanced between subjects. Half of the subjects in each of the eight experience/visual acuity groups were tested first at 400 meters, then at 800, 1,200, and 1,600 meters. The remaining subjects were tested at the 1,600-meter range first and moved successively closer.

RESULTS

The data from Experiment II were analyzed using both search times and the percentage of the targets correctly located (percent correct responses). The raw data are given in Appendix C.

Figure 6 presents the mean search times as a function of range and visual acuity for all subjects combined. Subjects with 20/20 acuity always found the targets at least twice as fast as subjects with 20/40 or 20/50 acuity and even 20/30 at ranges greater than about 1,000 meters. There was a very small number of data points for subjects with 20/40 and 20/50 acuity at long ranges since missing data could not be tabulated. Therefore, the shape of the curves is questionable in that region.

The data presented in Figure 7, where percent correct responses were plotted as a function of range and acuity for all subjects combined, are similar to the data in Figure 6. In this case, subjects with 20/40 or 20/50 acuity did not find targets at the longer ranges, while subjects with 20/20 acuity found 75% of them within the time limit. At the shortest range, 400 meters, all of the subjects found all of the targets.

Differences in performance as a function of masking are presented in Figures 8 and 9. In Figure 8 mean search times are presented as a function of masking and visual acuity for all subjects combined across ranges, and in Figure 9 percent correct responses are shown as a function of those factors. In both cases there is clearly a large effect due to masking. Also in both cases there was a greater performance degradation for 20/20 acuity than for 20/50 acuity. That may be due to the time limit imposed on the subject's search. The longest time possible was 0.5 minute and the lowest percent correct possible was 0, which tended to compress the curves at poor performance levels.

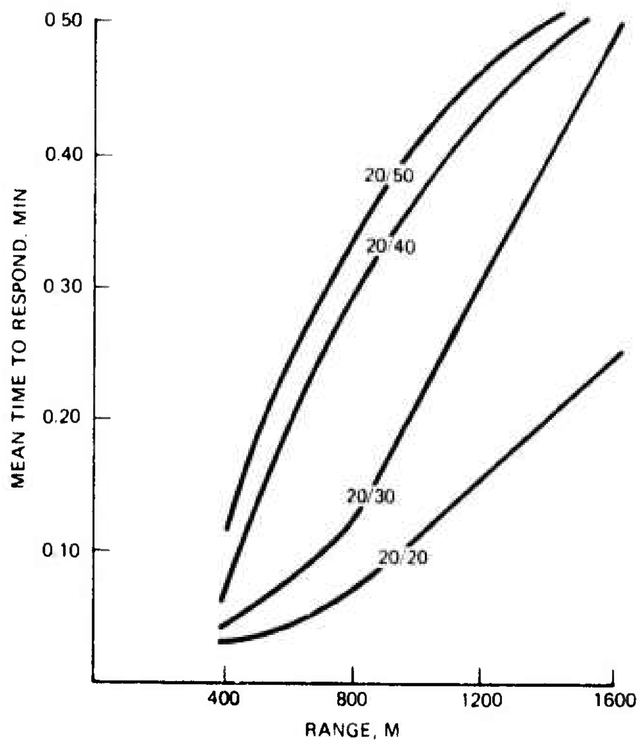

FIGURE 6. Search Time as a Function of Range and Visual Acuity. Data are combined across masking and subjects.

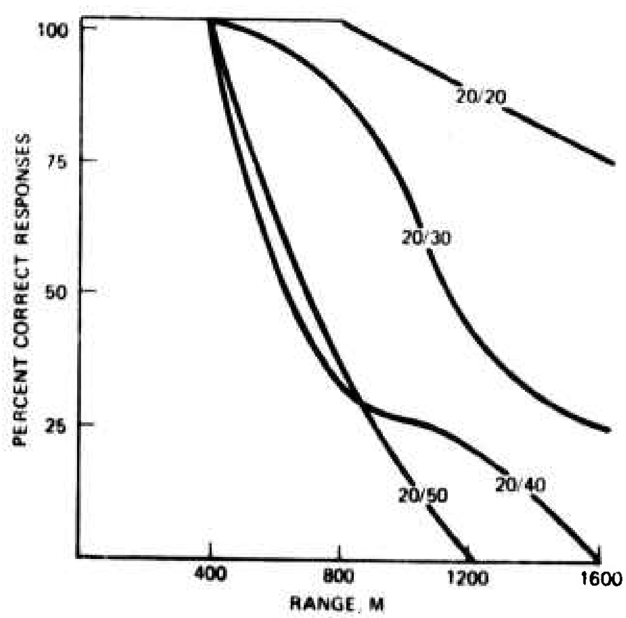

FIGURE 7. Percent Correct Responses as a Function of Range and Visual Acuity. Data are combined across masking and subjects.

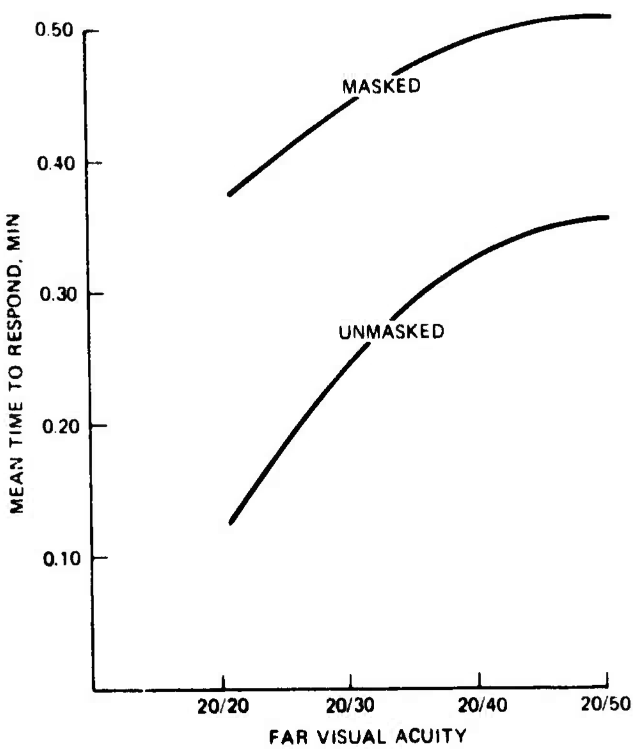

FIGURE 8. Mean Search Time as a Function of Visual Acuity and Masking. Data are combined across range and subjects.

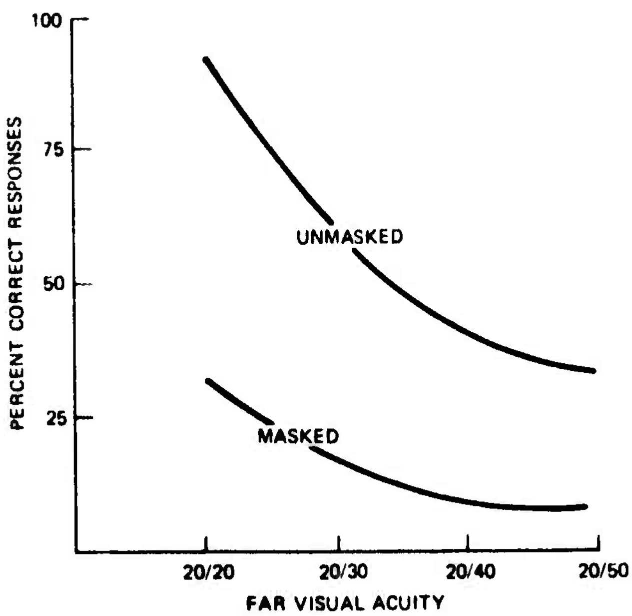

FIGURE 9. Percent Correct Responses as a Function of Visual Acuity and Masking. Data are combined across range and subjects.

An analysis of variance was conducted on both the percent-correct data and the mean-time-to-respond data. Only one of the summaries of the analyses is presented, since the results were virtually identical (Table 4). The analyses substantiate the results found in the preceding figures. Three of the factors were significant at the 0.001 level, indicating that the differences in observed performance due to range, visual acuity, and masking would occur by chance only one time in a thousand. In addition, significant interactions were found between range and visual acuity ($P < 0.01$), masking and visual acuity ($P < 0.001$), and masking and range ($P < 0.001$). These signify that: (1) the farther away the observer gets, the stronger the effect of visual acuity becomes; (2) the more a target is masked, the less differences in visual acuity affect performance; and (3) the more a target is masked, the smaller is the effect of range on performance.

The analysis of variance suggested again that experience has no significant effect on performance. In this case experience was defined differently than in Experiment I, yet it still seemed to be an unimportant variable.

An additional analysis of variance was made for supplementary evidence on the hypothesis that deficient color vision does not affect target acquisition performance. There was, again, no statistically significant difference between subjects with normal and deficient color vision ($F = 0.15$, $d_f = 1{,}6$).

TABLE 4. Summary of the Analysis of Variance on Search Time.

Source of Variation	MS	d_f	F	<P
Visual acuity (V)	1663.80	3	31.92	0.001
Subject group (G)	29.09	1	0.56	*
VXG	45.26	3	0.87	*
Error	52.12	24		
Range (R)	3183.80	3	129.52	0.001
RXV	67.59	9	2.75	0.01
RXG	33.42	3	1.36	*
RXVXG	46.70	9	1.90	0.10
Error	24.58	72		
Masking (M)	7358.42	1	232.86	0.001
MXV	361.75	3	11.45	0.001
MXG	34.59	1	1.09	*
MXVXG	88.35	3	2.80	0.10
Error	31.60	24		
RXM	343.63	3	10.38	0.001
RXMXV	245.31	9	7.41	0.001
RXMXG	13.91	3	0.42	*
RXMXVXG	47.84	9	1.44	*
Error	33.09	72		

* Probability greater than 0.10

DISCUSSION OF RESULTS

One aspect of the data that is of considerable interest is the effect masking had on target acquisition. In Experiment I, vertical masking had a moderate to strong effect. However, in Experiment II, there appeared to be a very strong effect due to masking the track and suspension system. The utility of such a camouflage technique is strongly suggested by the data and recommends further research in this area.

It should be noted, however, that if a target is masked, differences in performance due to visual acuity levels are reduced. Therefore, selection or maintenance of personnel on the basis of visual acuity may have less impact than expected if it is likely that targets will usually be masked. Similarly, there were little differences in performance due to visual acuity at the short ranges. So, if it is likely that, in combat, targets will be encountered at ranges less than about 500 meters, visual acuity may be of little importance as a selection criterion. The implications of this experiment, then, should be considered in the context of the potential field conditions that will exist.

Given the experimental conditions tested here, however, there is little doubt that visual acuity, range, and masking are important factors in the target acquisition process. Furthermore, it appears likely that, operational considerations being equal, it is possible to manipulate target acquisition performance to a large extent by varying the level of visual acuity of the observer. In other words, visual acuity could be used as one factor in the selection process with some evidence that target acquisition performance may be improved.

Appendix A

EXPERIMENTAL CONDITIONS

The matrices for the four designs (basic, changeover, augmented, and augmented-changeover) are presented on the following pages. The 16 conditions tested in each design are given, along with a sign matrix and second-order interactions confounded with main effects.

Each subject was tested on two conditions in each of the four designs. The two conditions administered depended upon the subject's particular levels of visual acuity, color vision, and depth perception. For example, if a subject had 20/20 far visual acuity, deficient color vision, and poor depth perception, he was given conditions AFHI and ADEFG from the first matrix. No other conditions in the basic matrix provide the necessary combination of the three subject factors. From the augmented design he was given AEFHIJK and ADFGJK, and so on for the other two designs.

BASIC DESIGN

Main Effects and Aliased Interactions*

Conditions	MEAN	CK BJ EG A	FK AJ EI B	AK FJ EH C	IK HJ EF D	BI CH AG DF E	BK CJ DE F	HK IJ AE G	GK DJ CE H	DK GJ BE I	GI DH CF AB J	DI GH BF AC K	CI BH FG AD	JK HI DG AF BC	EK FI AH CG BD	EJ AI FH BG CD
1. EJK	+	–	–	–	–	+	–	–	–	–	+	+	+	+	+	+
2. AFHI	+	+	–	–	–	–	+	–	+	+	–	–	–	+	+	+
3. BFGHK	+	–	+	–	–	–	+	+	+	–	–	+	+	–	–	+
4. ABEGIJ	+	+	+	–	–	+	–	+	–	+	+	–	–	–	–	+
5. CFGIJ	+	–	–	+	–	–	+	+	–	+	+	–	+	–	+	–
6. ACEGHK	+	+	–	+	–	+	–	+	+	–	–	+	–	–	+	–
7. BCEHI	+	–	+	+	–	+	–	–	+	+	–	–	+	+	–	–
8. ABCFJK	+	+	+	+	–	–	+	–	–	–	+	+	–	+	–	–
9. DGHIJK	+	–	–	–	+	–	–	+	+	+	+	+	–	+	–	–
10. ADEFG	+	+	–	–	+	+	+	+	–	–	–	–	+	+	–	–
11. BDEFIK	+	–	+	–	+	+	+	–	–	+	–	+	–	–	+	–
12. ABDHJ	+	+	+	–	+	–	–	–	+	–	+	–	+	–	+	–
13. CDEFHJ	+	–	–	+	+	+	+	–	+	–	+	–	–	–	–	+
14. ACDIK	+	+	–	+	+	–	–	–	–	+	–	+	+	–	–	+
15. BCDG	+	–	+	+	+	–	–	+	–	–	–	–	–	+	+	+
16. ABCDEFGHIJK	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+

*Only the second-order interactions and main effects are given. Each column would contain over 100 higher order interactions if they were all included.

A = Visual Acuity
B = Depth Perception
C = Color Vision
D = Observer Experience
E = Slant Range
F = Target Type
G = Masking
H = T/B Contrast
I = Pattern Painting
J = Target Orientation
K = Target Density

AUGMENTED DESIGN

Main Effects and Aliased Interactions*

Conditions	MEAN	CK BJ EG A	FK AJ EI B	AK FJ EH C	IK HJ EF D	BI CH AG DF E	BK CJ DE F	HK IJ AE G	GK DJ CE H	DK GJ BE I	GI DH CF AB J	DI GH BF AC K	CI BH FG AD	JK HI DG AF BC	EK FI AH CG BD	EJ AI FH BG CD
1. ABCDFGHI	+	+	+	+	+	−	+	+	+	+	−	−	−	−	−	−
2. BCDEGJK	+	−	+	+	+	+	−	+	−	−	+	+	+	−	−	−
3. ACDEIJ	+	+	−	+	+	+	−	−	−	+	+	−	−	+	+	−
4. CDFHK	+	−	−	+	+	−	+	−	+	−	−	+	+	+	+	−
5. ABDEHK	+	+	+	−	+	+	−	−	+	−	−	+	−	+	−	+
6. BDFIJ	+	−	+	−	+	−	+	−	−	+	+	−	+	+	−	+
7. ADFGJK	+	+	−	−	+	−	+	+	−	−	+	+	−	−	+	+
8. DEGHI	+	−	−	−	+	+	−	+	+	+	−	−	+	−	+	+
9. ABCEF	+	+	+	+	−	+	+	−	−	−	−	−	+	−	+	+
10. BCHIJ	+	−	+	+	−	−	−	−	[illegible]	+	+	+	−	−	+	+
11. ACGHJ	+	+	−	+	−	−	−	+	+	−	+	−	+	+	−	+
12. CEFGIK	+	−	−	+	−	+	+	+	−	+	−	+	−	+	−	+
13. ABGIK	+	+	+	−	−	−	−	+	−	+	−	+	+	+	+	−
14. BEFGHJ	+	−	+	−	−	+	+	+	+	−	+	−	−	+	+	−
15. AEFHIJK	+	+	−	−	−	+	+	−	+	+	+	+	+	−	−	−
16.	+	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−

* Only the second-order interactions and main effects are given. Each column would contain over 100 higher order interactions if they were all included.

A = Visual Acuity
B = Depth Perception
C = Color Vision
D = Observer Experience
E = Slant Range
F = Target Type
G = Masking
H = T/B Contrast
I = Pattern Painting
J = Target Orientation
K = Target Density

CHANGEOVER DESIGN

Main Effects and Aliased Interactions*

Conditions	MEAN	CK BJ EG A	FK AJ EI B	AK FJ EH C	IK HJ EF D	BI CH AG DF E	BK CJ DE F	HK IJ AE G	GK DJ CE H	DK GJ BE I	GI DH CF AB J	DI GH BF AC K	CI BH FG AD	JK HI DG AF BC	EK FI AH CG BD	EJ AI FH BG CD
1. EJK	+	–	–	–	–	+	–	–	–	–	+	+	+	+	+	+
2. AFHI	+	+	–	–	–	–	+	–	+	+	–	–	–	+	+	+
3. BFGHK	+	–	+	–	–	–	+	+	+	–	–	+	+	–	–	+
4. ABEGIJ	+	+	+	–	–	+	–	+	–	+	+	–	–	–	–	+
5. CFGIJ	+	–	–	+	–	–	+	+	–	+	+	–	+	–	+	–
6. ACEGHK	+	+	–	+	–	+	–	+	+	–	–	+	–	–	+	–
7. BCEHI	+	–	+	+	–	+	–	–	+	+	–	–	+	+	–	–
8. ABCFJK	+	+	+	+	–	–	+	–	–	–	+	+	–	+	–	–
9. DGHIJK	+	–	–	–	+	–	–	+	+	+	+	+	–	+	–	–
10. ADEFG	+	+	–	–	+	+	+	+	–	–	–	–	+	+	–	–
11. BDEFIK	+	–	+	–	+	+	+	–	–	+	–	+	–	–	+	–
12. ABDHJ	+	+	+	–	+	–	–	–	+	–	+	–	+	–	+	–
13. CDEFHJ	+	–	–	+	+	+	+	–	+	–	+	–	–	–	–	+
14. ACDIK	+	+	–	+	+	–	–	–	–	+	–	+	+	–	–	+
15. BCDG	+	–	+	+	+	–	–	+	–	–	–	–	–	+	+	+
16. ABCDEFGHIJK	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+

* Only the second-order interactions and main effects are given. Each column would contain over 100 higher order interactions if they were all included.

A = Observer Experience
B = Color Vision
C = Depth Perception
D = Visual Acuity
E = Target Density
F = Target Orientation
G = Pattern Painting
H = T/B Contrast
I = Mask[illegible]
J = Target Type
K = Slant Range

AUGMENTED-CHANGEOVFF. DESIGN

Main Effects and Aliased Interactions*

Conditions	MEAN	CK BJ EG A	FK AJ EI B	AK FJ EH C	IK HJ EF D	BI CH AG DF E	BK CJ DE F	HK IJ AE G	GK DJ CE H	DK GJ BE I	GI DH CF AB J	DI GH BF AC K	CI BH FG AD	JK HI DG AF BC	EK FI AH CG BD	EJ AI FH BG CD
1. ABCDFGHI	+	+	+	+	+	−	+	+	+	+	−	−	−	−	−	−
2. BCDEGJK	+	−	+	+	+	+	−	+	−	−	+	+	+	−	−	−
3. ACDEIJ	+	+	−	+	+	+	−	−	−	+	+	−	−	+	+	−
4. CDFHK	+	−	−	+	+	−	+	−	+	−	−	+	+	+	+	−
5. ABDEHK	+	+	+	−	+	+	−	−	+	−	−	+	−	+	−	+
6. BDFIJ	+	−	+	−	+	−	+	−	−	+	+	−	+	+	−	+
7. ADFGJK	+	+	−	−	+	−	+	+	−	−	+	+	−	−	+	+
8. DEGHI	+	−	−	−	+	+	−	+	+	+	−	−	+	−	+	+
9. ABCEF	+	+	+	+	−	+	+	−	−	−	−	−	+	−	+	+
10. BCHIJ	+	−	+	+	−	−	−	−	+	+	+	+	−	−	+	+
11. ACGHJ	+	+	−	+	−	−	−	+	+	−	+	−	+	+	−	+
12. CEFGIK	+	−	−	+	−	+	+	+	−	+	−	+	−	+	−	+
13. ABGIK	+	+	+	−	−	−	−	+	−	+	−	+	+	+	+	−
14. BEFGHJ	+	−	+	−	−	+	+	+	+	−	+	−	−	+	+	−
15. AEFHIJK	+	+	−	−	−	+	+	−	+	+	+	+	+	−	−	−
16.	+	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−

* Only the second-order interactions and main effects are given. Each column would contain over 100 higher order interactions if they were all included.

A = Observer Experience
B = Color Vision
C = Depth Perception
D = Visual Acuity
E = Target Density
F = Target Orientation
G = Pattern Painting
H = T/B Contrast
I = Masking
J = Target Type
K = Slant Range

Appendix B

INSTRUCTIONS TO THE SUBJECTS

You are about to help us test some factors which seem to affect the visual identification of targets.

Here are the targets for which you will be searching and which you will try to identify. As you can see, half of them are tanks and half are armored personnel carriers. These targets will be located randomly in the search area which you can see through the small window. On any given trial one or three targets will be in the search area, but they will not be mixed, i.e., only tanks or APCs will be in the search area, but not both. Also, pattern-painted and solid-colored vehicles will not be placed on the terrain model at the same time. Sometimes the targets will be in the open and at other times they will be partially hidden behind trees.

Your task will be to quickly locate a target and then make an accurate identification of it as either a tank or an APC. Each trial will last one minute. If you do not respond within the time limit, time will be called and the trial will be terminated.

The procedure will be as follows. While this shutter is in the closed position like this, a target or targets will be placed in the search area. When you hear the word "ready" pull this string to open the shutter and start the timer. Immediately begin searching for a target. As soon as you find one, flip one of these switches indicating which type of target you think it is. After you have flipped the switch, tell us in which section of the terrain you found the target. You will have to close the shutter and reset the switch after each trial.

Remember, flip the switch first, then describe the target location.

Do you have any questions?

Appendix C

RAW DATA
(Correct and Incorrect Responses)*

	FVA		Masking: No, Range 400	800	1200	1600	Masking: Yes, Range 400	800	1200	1600
No Experience	20/20	1	1	1	0	0	1	0	0	1
		2	1	1	1	1	1	0	0	0
		3	1	1	1	1	1	0	0	0
		4	1	1	1	1	1	1	0	0
	20/30	5	1	0	0	0	0	0	0	0
		6	1	1	0	1	0	0	0	0
		7	1	1	1	1	0	0	0	0
		8	1	1	1	1	0	0	0	0
	20/40	9	1	0	0	0	0	0	0	0
		10	1	0	0	0	0	0	0	0
		11	1	0	0	0	1	0	0	0
		12	1	0	0	0	0	0	0	0
	20/50	13	1	0	0	0	0	0	0	0
		14	1	1	0	0	0	0	0	0
		15	1	0	0	0	1	0	0	0
		16	1	1	0	0	1	0	0	0
Experience	20/20	17	1	1	1	1	1	1	0	1
		18	1	1	1	0	1	0	0	0
		19	1	1	1	1	1	1	0	0
		20	1	1	1	1	1	0	0	0
	20/30	21	1	1	0	0	0	0	0	0
		22	1	1	0	0	1	0	0	0
		23	1	1	1	0	0	0	0	0
		24	1	1	0	0	0	0	0	0
	20/40	25	1	1	1	0	1	0	0	0
		26	1	0	1	0	0	0	0	0
		27	1	0	0	0	0	0	0	0
		28	1	1	0	0	1	0	0	0
	20/50	29	1	0	0	0	0	0	0	0
		30	1	0	0	0	1	0	0	0
		31	1	1	0	0	0	0	0	0
		32	1	1	0	0	0	0	0	0

* 1 = correct response, 0 = incorrect response or absence of a response.

RAW DATA*

(Search Times)

	FVA		Masking: No, Range 400	800	1200	1600	Masking: Yes, Range 400	800	1200	1600
No Experience	20/20	1	1.8	1.2	30.0	30.0	3.6	30.0	30.0	28.2
		2	1.8	1.2	3.0	5.4	2.4	30.0	30.0	30.0
		3	1.2	3.0	6.6	25.2	12.0	30.0	30.0	30.0
		4	1.2	1.8	3.0	5.4	2.4	8.3	30.0	
	20/30	5	2.4		30.0	30.0			30.0	30.0
		6	1.8	6.6	30.0	16.2	30.0	30.0		30.0
		7	2.4	1.8	9.6	3.0		30.0	30.0	30.0
		8	3.0	5.4	6.0	15.0				
	20/40	9	1.8		30.0	30.0	30.0	30.0	30.0	
		10	2.4		30.0			30.0	30.0	30.0
		11	6.0	30.0		30.0	18.0		30.0	
		12	2.4	30.0	30.0	30.0	30.0	30.0	30.0	30.0
	20/50	13	2.4	30.0	30.0	30.0	30.0	30.0	30.0	30.0
		14	10.8	12.0	30.0	30.0		30.0	30.0	30.0
		15	3.3	30.0	30.0	30.0	16.8	30.0	30.0	30.0
		16	19.2	18.0	30.0		28.8	30.0	30.0	30.0
Experience	20/20	17	1.8	16.2	18.0	17.4	7.2	8.4	30.0	25.8
		18	1.2	2.4	24.0		7.2	30.0		30.0
		19	1.8	1.8	7.2	3.0	2.4	8.4	30.0	30.0
		20	1.2	1.8	7.8	10.8	1.8	30.0	30.0	30.0
	20/30	21	2.4	6.6		30.0		30.0	30.0	
		22	1.2	18.0		30.0	5.4	30.0		30.0
		23	1.2	3.6	7.2					
		24	5.4	7.2	30.0		30.0	30.0		30.0
	20/40	25	1.8	6.0	15.0	30.0	5.4	30.0		
		26	3.0	30.0	12.6	30.0	30.0			30.0
		27	3.0	30.0	30.0	30.0	30.0		30.0	
		28	4.2	8.4	30.0	30.0	19.8			30.0
	20/50	29	1.2	30.0	30.0	30.0	30.0		30.0	30.0
		30	1.8	30.0	30.0	30.0	13.8	30.0	30.0	30.0
		31	1.8	30.0	30.0	30.0	30.0	30.0	30.0	30.0
		32	14.4	22.8	30.0					

* Blank spaces indicate false detection.

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